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# EVALUATION PROGRAM for SECONDARY SPACECRAFT CELLS

GENERAL PERFORMANCE TEST
OF
GENERAL ELECTRIC COMPANY
20 AMPERE–HOUR
NICKEL–CADMIUM CELLS

prepared for
GODDARD SPACE FLIGHT CENTER

CONTRACT W12,397

QUALITY EVALUATION LABORATORY

NAD CRANE, INDIANA

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UNITED STATES NAVAL AMMUNITION DEPOT
CRANE, INDIANA

EVALUATION PROGRAM
FOR
SECONDARY SPACECRAFT CELLS

GENERAL PERFORMANCE TEST
OF
GENERAL ELECTRIC 20 AMPERE-HOUR
NICKEL-CADMIUM SECONDARY
SPACECRAFT CELLS

QE/C 69-968 24 NOVEMBER 1969

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By direction

Enclosure (1)

# REPORT BRIEF
# RESULTS OF GENERAL PERFORMANCE TESTS
# OF
# 20 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS
# MANUFACTURED BY
# GENERAL ELECTRIC COMPANY

Ref: (a) National Aeronautics and Space Administration Purchase Order Number W12,397
(b) NASA ltr BRA/VBK/pad of 25 September 1961 w/BUWEPS first end FQ-1:WSK of 2 October 1961 to CO NAD Crane
(c) NASA memo ERS of 27 June 1967 to NAD Crane
(d) Grumman Aircraft Engineering Corporation OAO Project memorandum 64-108 of 30 November 1964

## I. TEST ASSIGNMENT BRIEF

A. In compliance with references (a) and (b), evaluation of sealed nickel-cadmium cells was begun on 21 January 1969 according to the program outline of reference (c). Environmental tests were conducted according to reference (d) on four of the five cells tested. Only four cells were available at the time of the scheduled environmental test. When the fifth cell (529-094) was available, Goddard Space Flight Center instructed this activity to place the cells on test immediately--eliminating the environmental test for the fifth cell.

B. The object of this evaluation program is to gather specific information concerning sealed nickel-cadmium cells designed for use in spacecraft. Information concerning the performance characteristics and limitations under various electrical and environmental conditions will be of interest to power system designers and users.

C. Five cells were purchased by the National Aeronautics and Space Administration (NASA) from the General Electric Company, Gainesville, Florida. These cells are rated at 20 ampere-hours by the manufacturer.

## II. SUMMARY OF RESULTS

A. The four cells subjected to the environmental tests (vibration, mechanical shock and acceleration) were capable of withstanding all the requirements. The one cell omitted from the environmental testing showed no significant capacity or voltage difference from those cells that experienced the testing.

B. Charge and Discharge Voltage Characteristics:

1. The most efficient charge rate at each of four temperatures was obtained by a series of tests; the series included a total of 28 different combinations of charge rate and temperature variations while the discharge rate was held constant at c/2. The following table summarizes the charge rate and end-of-charge voltage characteristics which delivered the maximum capacity at each temperature.

| Temp | Charge Rate | End-of-Charge Cell Voltage Range | End-of-Charge Aux Electrode Voltage Range | Max Capacity Ampere-Hours |
|---|---|---|---|---|
| -20° C | c/10 | 1.45 to 1.96 | 0.013 to 0.501 | 17.8 |
| 0° C | 2c | 1.42 to 1.78 | 0.027 to 0.339 | 19.2 |
| 20° C | c/1 | 1.40 to 1.58 | 0.281 to 0.118 | 18.2 |
| 40° C | c/1 | 1.36 to 1.52 | 0.274 to 0.555 | 17.3 |

2. The most efficient discharge rate at each of four temperatures was obtained in a series of tests; the series included a total of 28 different combinations of discharge rate and temperature variation while the charge rate was held constant at the predetermined rate which gave maximum capacity at each of the four temperatures. The average $\Delta T$'s (temperature differences from ambient) for the rates c/2, c/1 and 2c were respectively +1°, +2° and +6° C. The following table summarizes the discharge rate and end-of-discharge auxiliary electrode voltage characteristics which delivered maximum capacity.

| Temp | Charge Rate | Discharge Rate | End-of-Discharge Aux Electrode Voltage Range | Max Capacity Ampere-Hours |
|---|---|---|---|---|
| -20° C | c/10 | c/20 | 0.004 to 0.120 | 19.4 |
| 0° C | 2c | c/20 | 0.010 to 0.238 | 19.2 |
| 20° C | c/1 | c/10 | 0.014 to 0.069 | 19.1 |
| 40° C | c/1 | c/10 | 0.018 to 0.283 | 19.6 |

C. Overcharge Characteristics:

1. The lower the ambient temperature of the cells, the higher were the stabilized cell voltages during overcharge. This was true at each of the seven overcharge rates.

## III. CONCLUSIONS

A. The data indicates that maximum efficiency could be obtained from these cells by charging at the 2c rate, discharging between the rates of c/10 and c/20, and maintaining an ambient temperature of 0° C.

B. The maximum signal voltage on the auxiliary electrode occurs under conditions practically opposite that of maximum cell efficiency. The charge rate should be c/10; the discharge rate should be 2c; and the ambient temperature should be 40° C to obtain the maximum signal voltage.

C. Cell voltage, on charge, increases as ambient temperature decreases--no exceptions.

# RESULTS OF GENERAL PERFORMANCE TESTS OF 20 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS WITH AUXILIARY ELECTRODE MANUFACTURED BY GENERAL ELECTRIC COMPANY

## I. INTRODUCTION

A. The General Performance Tests on five cells were begun on 21 January 1969 and completed on 19 April 1969. Only four of the five cells experienced the environmental tests of vibration, shock and acceleration. Cell 529-094 was not available for scheduled environmental testing. Due to urgent need for data in relation to the OAO program, this activity was instructed by Goddard Space Flight Center to immediately begin electrical tests when the fifth cell was available. This eliminated rescheduling delays.

## II. TEST CONDITIONS

A. These tests were performed at existing relative humidity and atmospheric pressure, and at four specific temperatures. The tests and test temperatures were as follows:

1. Random vibration at room ambient temperature.

2. Sinusoidal vibration at room ambient temperature.

3. Mechanical shock at room ambient temperature.

4. Acceleration at room ambient temperature.

5. Charge and discharge voltage characteristics at various specified charge rates at -20° C, 0° C, 20° C and 40° C.

6. Charge and discharge voltage characteristics at various specified discharge rates at -20° C, 0° C, 20° C and 40° C.

7. Overcharge characteristics at -20° C, 0° C, 20° C and 40° C.

B. All charging was by constant current to 100 percent of the manufacturer's rated capacity, c, except for one intermediate cycle between each of three different phases of testing. These cycles were performed at room ambient, and the charge was constant current for 16 hours at the c/10 rate. All discharges were constant current to 0.0 volts.

## III. CELL IDENTIFICATION AND DESCRIPTION

A. The five cells tested were identified by the manufacturer's serial numbers 529-094, 529-237, 529-233, 606-003 and 616-003.

B. The cell containers and covers are made of stainless steel. Both terminals of each cell are insulated from the cell cover by new expansion joint type ceramic seals and protrude through the cover as solder type terminals. A stainless steel tab is welded to the cover as the terminal for the auxiliary electrode which is welded to the inside of the cell container.

## IV. TEST PROCEDURES AND RESULTS

A. Random Vibration Test:

1. Each cell was charged at the c/10 rate for 16 hours, following which they were individually mounted in a rigid test fixture attached to the table of an M. B. Electronics Model C-10 vibrator. The amplitude or acceleration was monitored on the test fixture near the mounting points.

2. Each cell was subjected to gaussian random vibration applied to each axis for 8 minutes with the "g-peaks" clipped at three times the root-mean-square acceleration as specified in the schedule. The vibration was applied successively to the Z, X and Y axes. With a cell installed, the control accelerometer response was equalized with peak-notch filterization such that the specified power spectral density (PSD) values were within ± 3 db throughout the frequency band.

RANDOM VIBRATION SCHEDULE

| Longitudinal Axis | | Lateral Axis | |
|---|---|---|---|
| Frequency Range Hz | PSD Level $g^2/Hz$ | Frequency Range Hz | PSD Level $g^2/Hz$ |
| 15-70 | 0.030 | 15-70 | 0.030 |
| 70-400 | 0.0225 | 70-150 | 0.0225 |
| 400-800 | 0.045 | 150-2000 | 0.030 |
| 800-2000 | 0.030 | | |

3. During the applied vibration, the cells were discharged at the c/2 rate. The discharge current and the terminal voltage were monitored for evidence of cell malfunction during the applied vibration. After the vibration test, the cells were visually examined for evidence of mechanical damage.

4. There was no evidence of damage or malfunction of the four cells due to the random vibration test.

B. Sinusoidal Vibration Test:

1. Each cell was prepared as described in paragraph IV.A.1.

2. Each cell was subjected to sinusoidal vibration at a sweep rate of one octave per minute with two exposures. The vibration was applied successively to the Z, X and Y axes as specified in the following schedule.

SINUSOIDAL SWEEP SCHEDULE

| Frequency Range Hz | Level |
|---|---|
| 5-8 | 0.5" D.A. |
| 9-14 | Linear decrease to 0.2" D.A. |
| 15-54 | 0.2" D.A. |
| 55-2000 | 30 g's |

3. During the applied vibration, the cells were discharged at the c/5 rate. The discharge current and the terminal voltage were monitored for evidence of cell malfunction during the applied vibration. After the vibration test, the cells were visually examined for evidence of mechanical damage.

4. There was no evidence of damage or malfunction of the four cells due to the sinusoidal vibration.

C. Mechanical Shock Test:

1. Each cell was charged at the c/10 rate for 16 hours. The cells were then individually mounted in a rigid test fixture attached to the Barry Type 16805 Shock Machine.

2. Each cell was subjected to two, half-sine wave shock pulses of 30 g ± 10 percent amplitude in the Z, X and Y axes. The

time duration of the two pulses were 6 and 12 milliseconds ± 10 percent, respectively.

3. During the shock test, the cells were discharged at the c/2 rate. The discharge current and the terminal voltage were monitored during the shock test for evidence of malfunction of any cells.

4. At the conclusion of the test, the cells were examined for evidence of mechanical damage.

5. There was no evidence of damage or malfunction of the four cells due to the mechanical shock tests.

D. Acceleration Test:

1. Each cell was charged at the c/10 rate for 16 hours. The cells were then individually mounted in a rigid test fixture attached to the Genisco Model C-159 Centrifuge.

2. Each cell was subjected for 4.5 minutes per direction, of each axis, to acceleration at the g levels specified below.

| G Level | Axis |
|---|---|
| 11.3 | +X |
| 2.3 | ±Y, ±Z |
| 3.0 | -X |

3. During the acceleration tests, the cells were discharged at the c/2 rate. The discharge current and the terminal voltage were monitored for evidence of cell malfunction during the acceleration test periods.

4. At the conclusion of the tests, the cells were examined for mechanical damage.

5. There was no evidence of damage or malfunction of the four cells due to the acceleration tests.

E. Cell Preparation:

1. The five cells were prepared in the following manner for the charge and discharge voltage characteristics test and the overcharge characteristics test.

a. Each cell was restrained between two 1/4-inch steel plates.

b. A thermocouple was attached between the center of one outside surface of the cell and the adjacent plate.

c. A 300-ohm resistor was connected between the auxiliary electrode tab and the negative terminal of each cell. The auxiliary electrode voltage was monitored across this resistor.

F. Charge and Discharge Voltage Characteristics:

1. At specified charge rates:

a. The cells were discharged at the c/2 rate at room temperature. Each cell, in turn, was removed from the circuit when its voltage reached 0.0 volt, and was then shorted for a period of 30 to 60 minutes. The cells were then recharged at the c/10 rate for 16 hours. Following a 15-minute open circuit stand, the cells were given a capacity test discharge at room temperature at the c/2 rate to 0.0 volt as above, and again shorted for a period of 30 to 60 minutes.

b. The cells were then placed in a controlled temperature chamber and allowed to stabilize at 40° C.

c. The cells were then recharged at the c/40 rate to 100 percent of the manufacturer's rated capacity. Following a 15-minute stand, the cells were discharged at the c/2 rate to 0.0 volt each and shorted for a period of 30 to 60 minutes.

d. Paragraph IV.F.1.c. was repeated for c/20, c/10, c/5, c/2, c/1 and 2c charge rates.

e. Upon completion of the above sequence at 40° C with the seven charge rates, the tests of paragraphs IV.F.1.c. and IV.F.1.d. were repeated at 20° C, 0° C and -20° C.

f. Test Results:

(1) The test results are shown graphically in Figures 1 through 7. Because of the large volume of data, only average values of the recorded data are plotted. More detailed data is available upon request. The average values of cell voltages, auxiliary electrode voltages, and temperature differences (between cell skin and ambient temperatures) taken throughout the charge and discharge periods for each fixed charge rate at each of the four ambient temperatures were

plotted against the corresponding percentage of the manufacturer's rated capacity. These graphs show the effects of each of the four ambient temperatures on the cell voltage, the auxiliary electrode voltage, the cell temperature, and the ampere-hour efficiency of the cells discharge at a fixed rate of c/2 following a 100 percent charge at each of the seven charge rates.

(2) Figure 8 is a summary of the capacities delivered following each of the seven charge rates to 100 percent of the manufacturer's rated capacity. Capacities are plotted as a percentage of the manufacturer's rated capacity. This figure shows that maximum capacity for all charge rates except c/40 and c/1 were delivered at 0° C. Maximum capacities for these charge rates were delivered at 20° C. It also shows for each ambient temperature the charge rate which will deliver the maximum capacity on the following discharge. The charge rate that resulted in the maximum delivered capacity at -20° C, 0° C, 20° C and 40° C was c/10, 2c, c/1, and c/1 respectively.

(3) Figure 9 compares the end-of-charge voltage with the log of each of the seven charge rates. It shows that the maximum auxiliary electrode signal for the -20° C ambient occurred at the 2c charge rate: 0° C at 2c, 20° C at c/1, and 40° C at c/1. The two lower temperatures give relatively uniform signal increases with increasing charge rates. However, the two higher temperatures produce graphs that are roughly mirror images of each other; the 40° C curve gave a maximum signal voltage at the c/10 rate while the 20° C curve gave a minimum signal voltage at the c/5 rate.

2. At specified discharge rates:

a. Following the above tests, the cells were allowed to stabilize at room ambient. The cells were then recharged at the c/10 rate for 16 hours. Following a 15-minute stand, the cells were given a capacity discharge at c/2. Each cell, in turn, was removed from the circuit when its voltage reached 0.0 volt and was then shorted for a period of 30 to 60 minutes.

b. The cells were then allowed to stabilize at 40° C.

c. The cells were charged at the c/1 rate (determined in paragraphs IV.F.1.c. through IV.F.1.e. to give maximum capacity) to 100 percent of the manufacturer's rated capacity. Following a 15-minute stand, each cell was discharged at the c/40 rate to 0.0 volt and then shorted for a period of 30 to 60 minutes.

d. Paragraph IV.F. 2.c. was repeated for each of the c/20, c/10, c/5, c/2, c/1 and 2c discharge rates.

e. Upon completion of the above sequence with the seven discharge rates, the tests of paragraphs IV.F.2.c. and IV.F.2.d. were repeated at 20° C with a c/1 charge rate, at 0° C with a 2c charge rate and at -20° C with a c/10 charge rate.

f. Test Results:

(1) The results are shown graphically in Figures 10 through 16. The average values of cell voltages, auxiliary electrode voltages, and temperature differences (between cell skin and ambient temperatures) taken throughout the discharge periods for each fixed discharge rate at each of the four ambient temperatures were plotted against the corresponding percentage of the manufacturer's rated capacity. These graphs show the effects of each of the four ambient temperatures on the cell voltage, the auxiliary electrode voltage, the cell temperature, and the ampere-hour efficiency of the cells discharged at each of the seven fixed discharge rates following a charge previously determined to be the most efficient at each of the four temperatures.

(2) Figure 17 is a summary of the capacities delivered at the seven discharge rates. Capacities are plotted as a percentage of the manufacturer's rated capacity. It also shows the maximum capacity delivered at each ambient temperature. The discharge rate that delivered the maximum capacity at each of the four ambient temperatures, -20° C, 0° C, 20° C and 40° C was c/20, c/20, c/10 and c/10 respectively.

3. Figure 18 is a family of curves showing the end-of-discharge voltage signal for the auxiliary electrode compared to the log of each of the seven discharge rates. For all temperatures except 20° C, the signal voltage approached a maximum when the cell was discharged at the 2c rate. The maximum was reached at the c/1 discharge rate for the 20° C ambient temperature.

G. Overcharge Characteristics:

1. Upon completion of the charge and discharge voltage characteristics tests, the discharged cells were allowed to stabilize at room temperature. The cells were then recharged at the c/10 rate for 16 hours. Following a 15-minute stand each cell was given a capacity discharge at the c/2 rate to 0.0 volt and then shorted for 30 to 60 minutes.

2. Four cells were then allowed to stabilize, one in each of the four ambient test temperatures (-20° C, 0° C, 20° C and 40° C). The fifth cell was kept as a spare in the event of a catastrophic failure.

3. The four cells at their respective temperatures were then subjected to the overcharge sequence listed below:

a. Charge at c/10 for 16 hours; wait 1 hour.

b. Charge at c/40 until the cell voltage stabilizes.

c. Charge at c/20 until the cell voltage stabilizes.

d. Charge at c/10 until the cell voltage stabilizes.

e. Charge at c/5 until the cell voltage stabilizes.

f. Charge at c/2 until the cell voltage stabilizes.

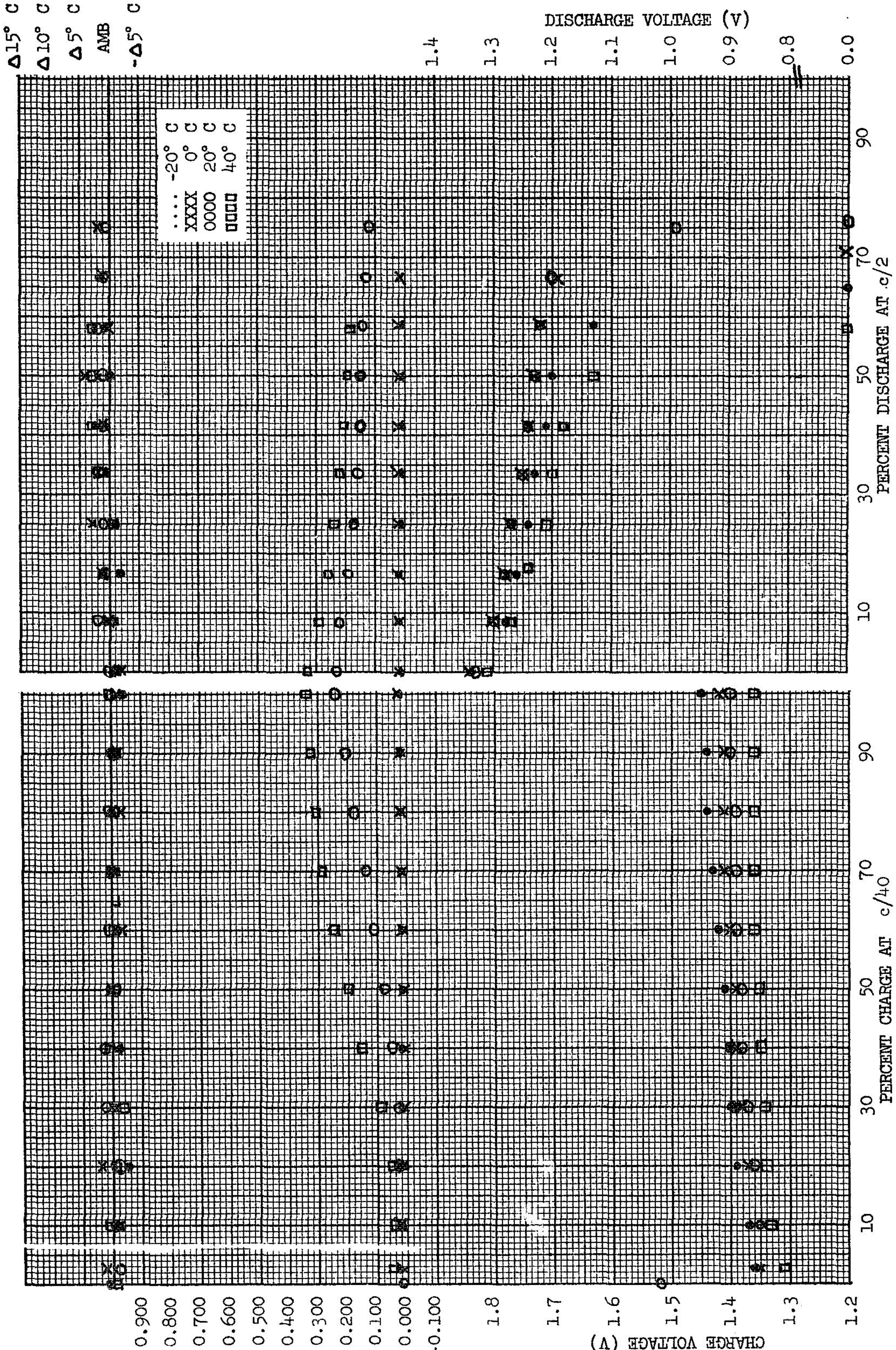
g. Charge at c/1 until the cell voltage stabilizes.

h. Charge at 2c until the cell voltage stabilizes.

4. All charging was at constant current with no voltage limit.

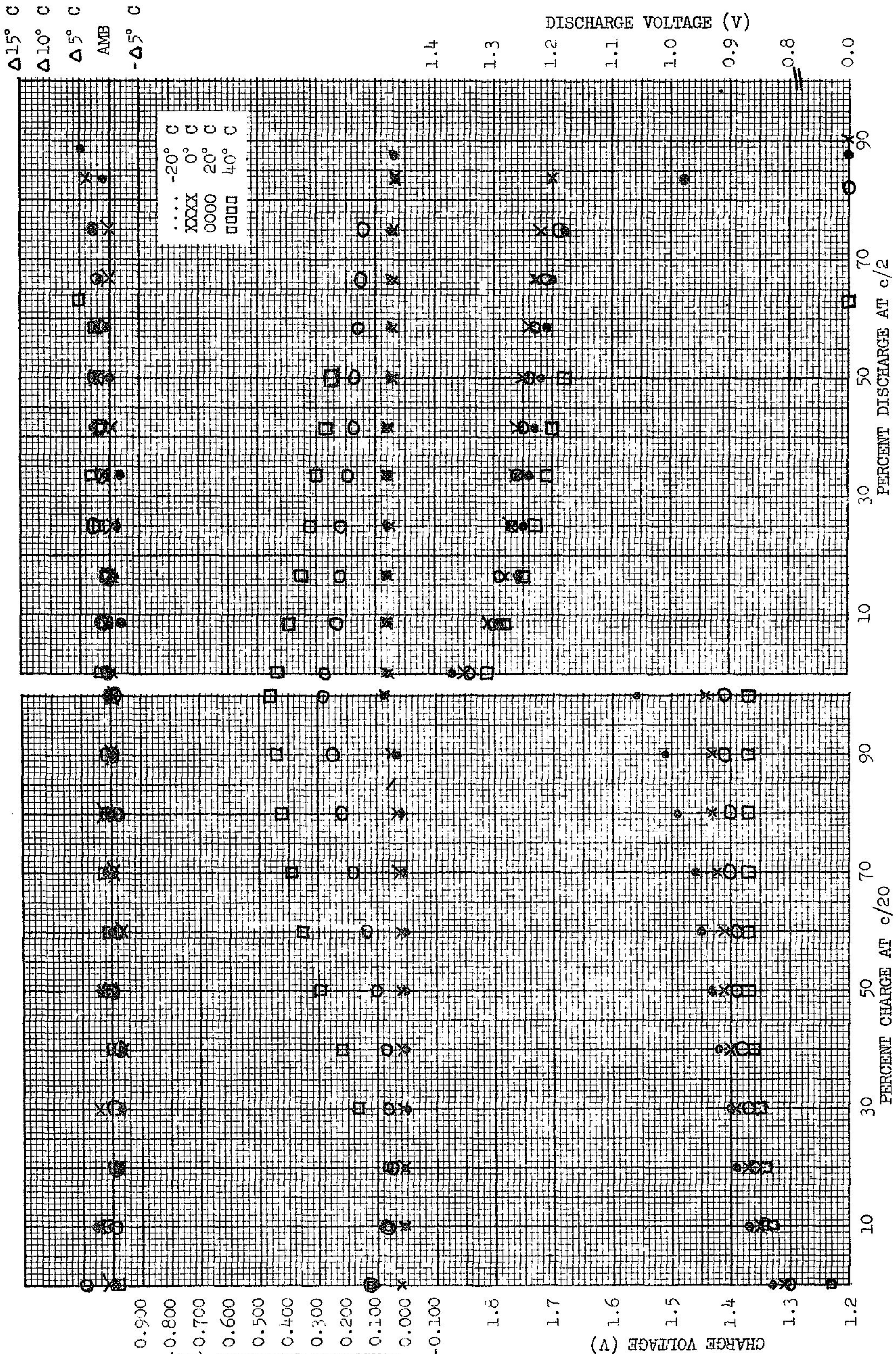
5. A drop in voltage of 0.05 volt or more from the highest value observed, or temperatures above 77° C terminated the tests at the particular ambient temperature.

6. The results are shown graphically in Figure 19 as a plot of the cell and auxiliary electrode voltages versus the log of the charging current. Figure 20 is a plot of the difference between the cell temperature and the ambient temperature versus the log of the charging current.



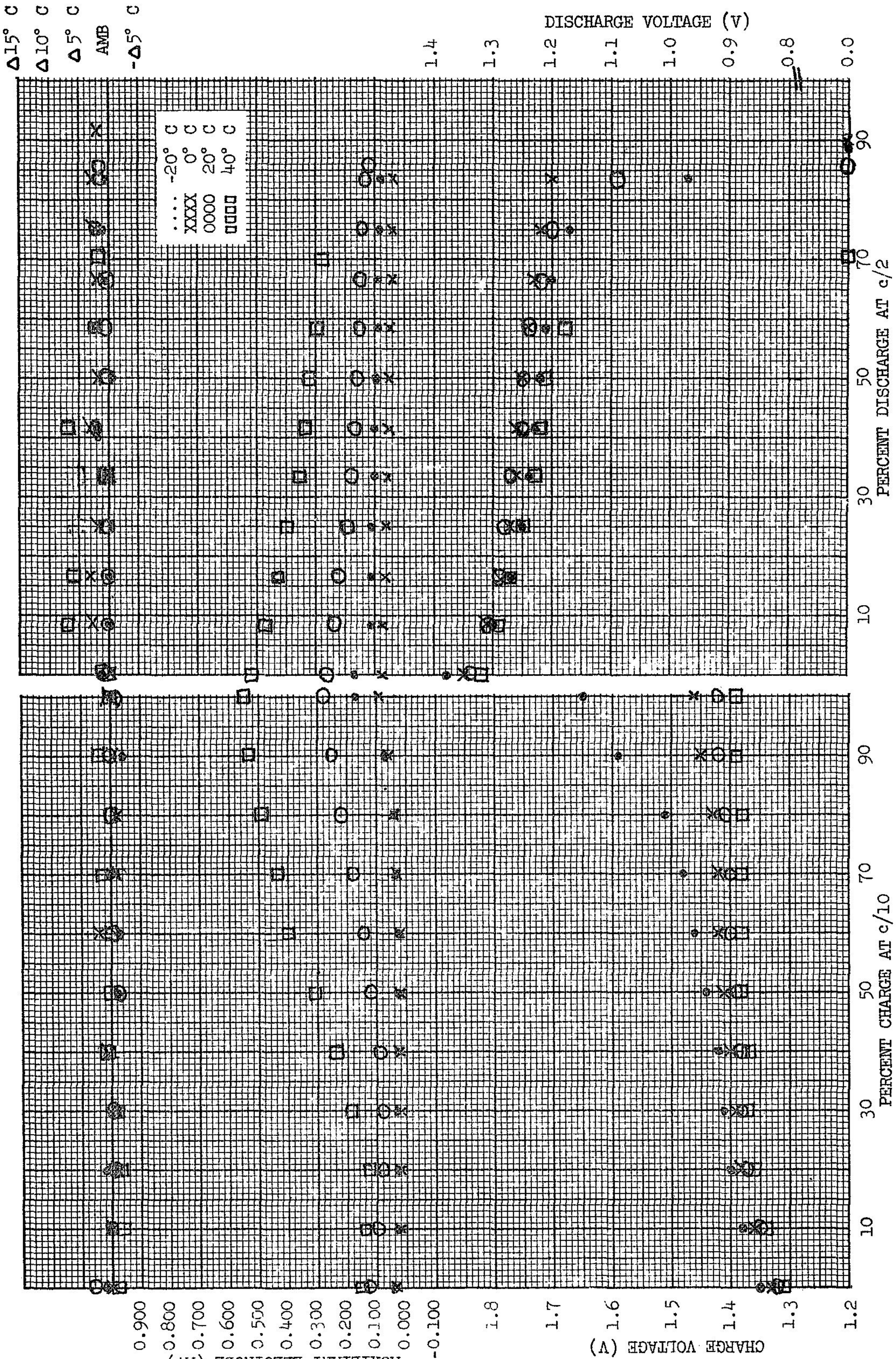

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 1



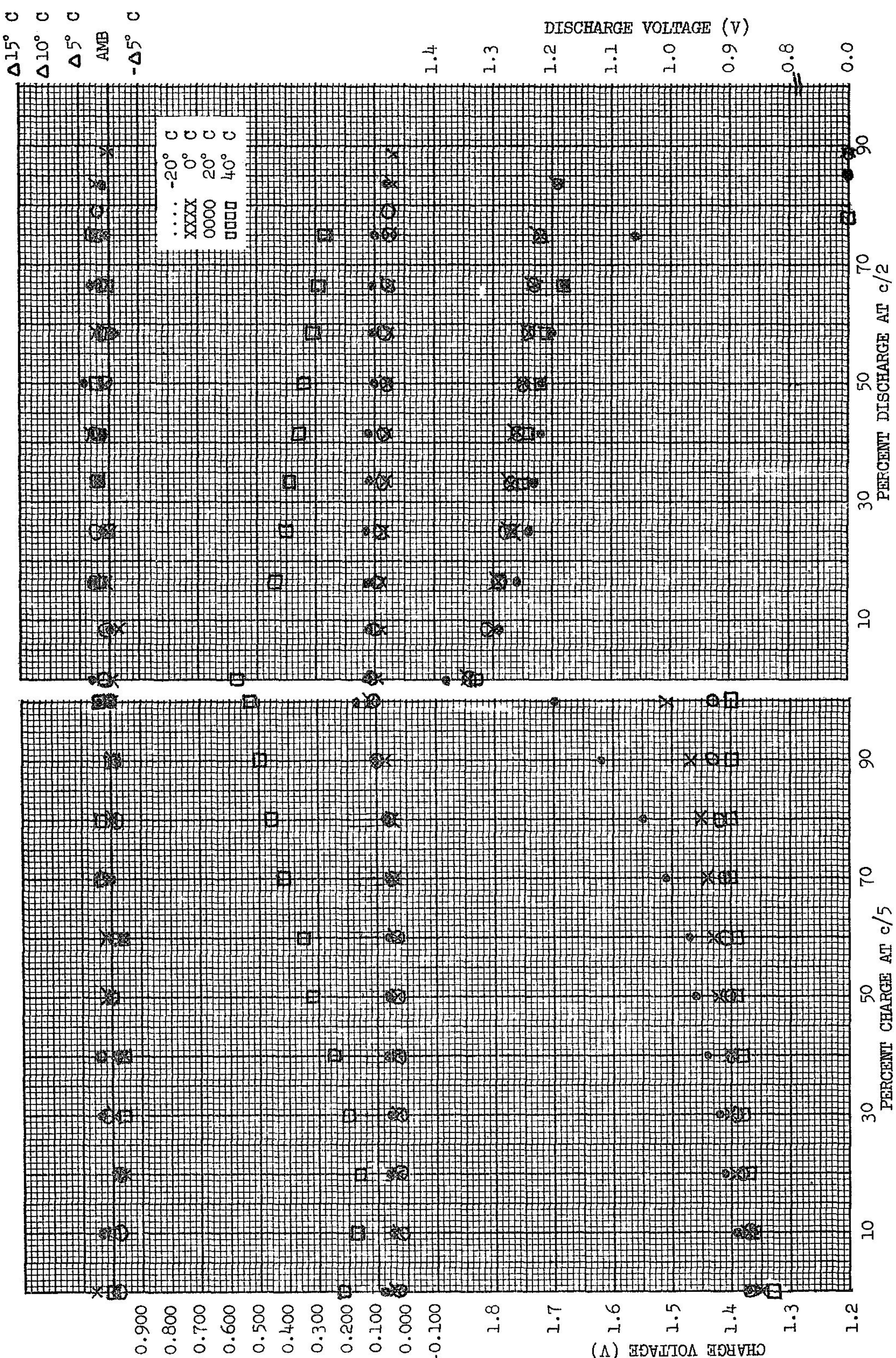

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 2.




VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 3




VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 4

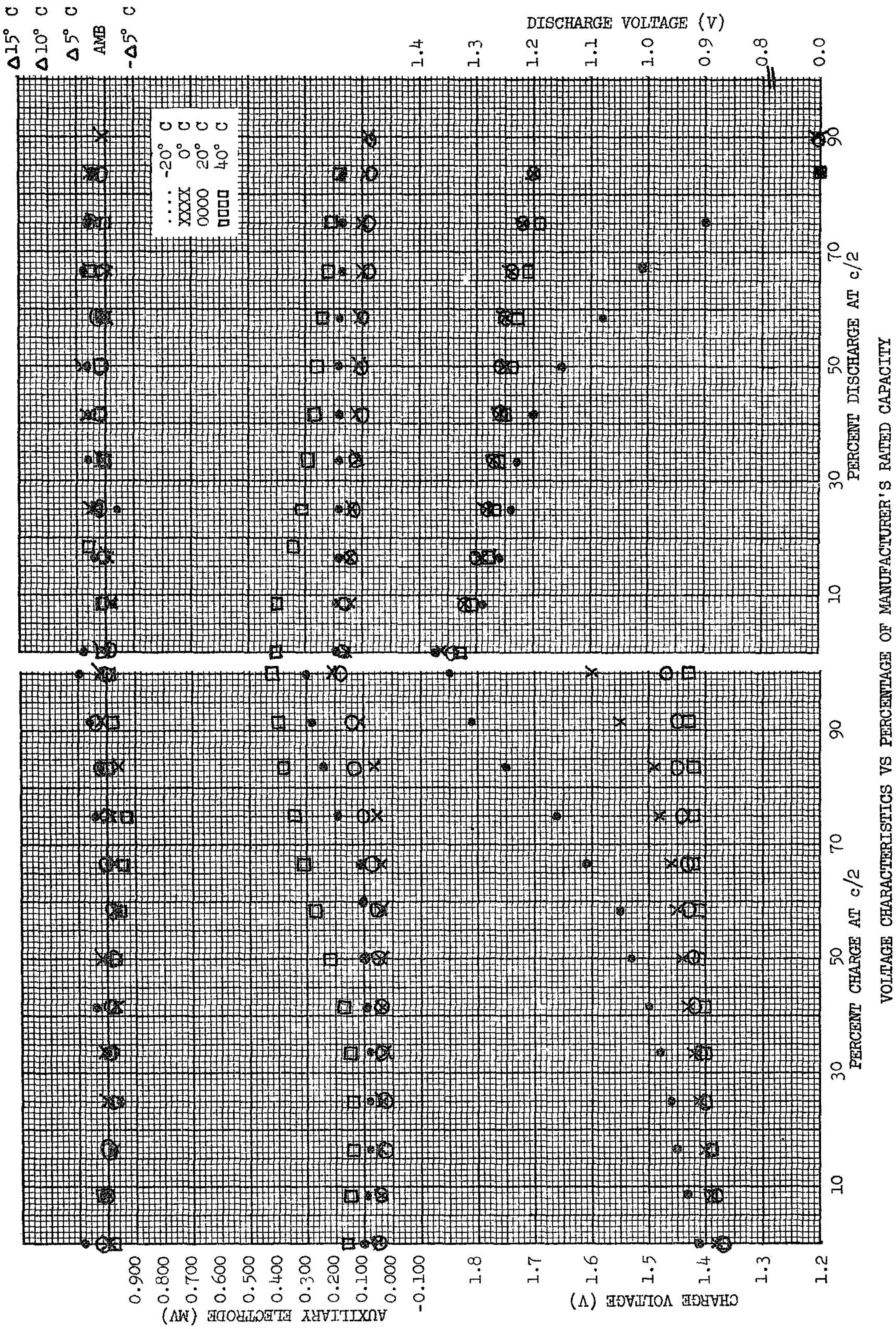
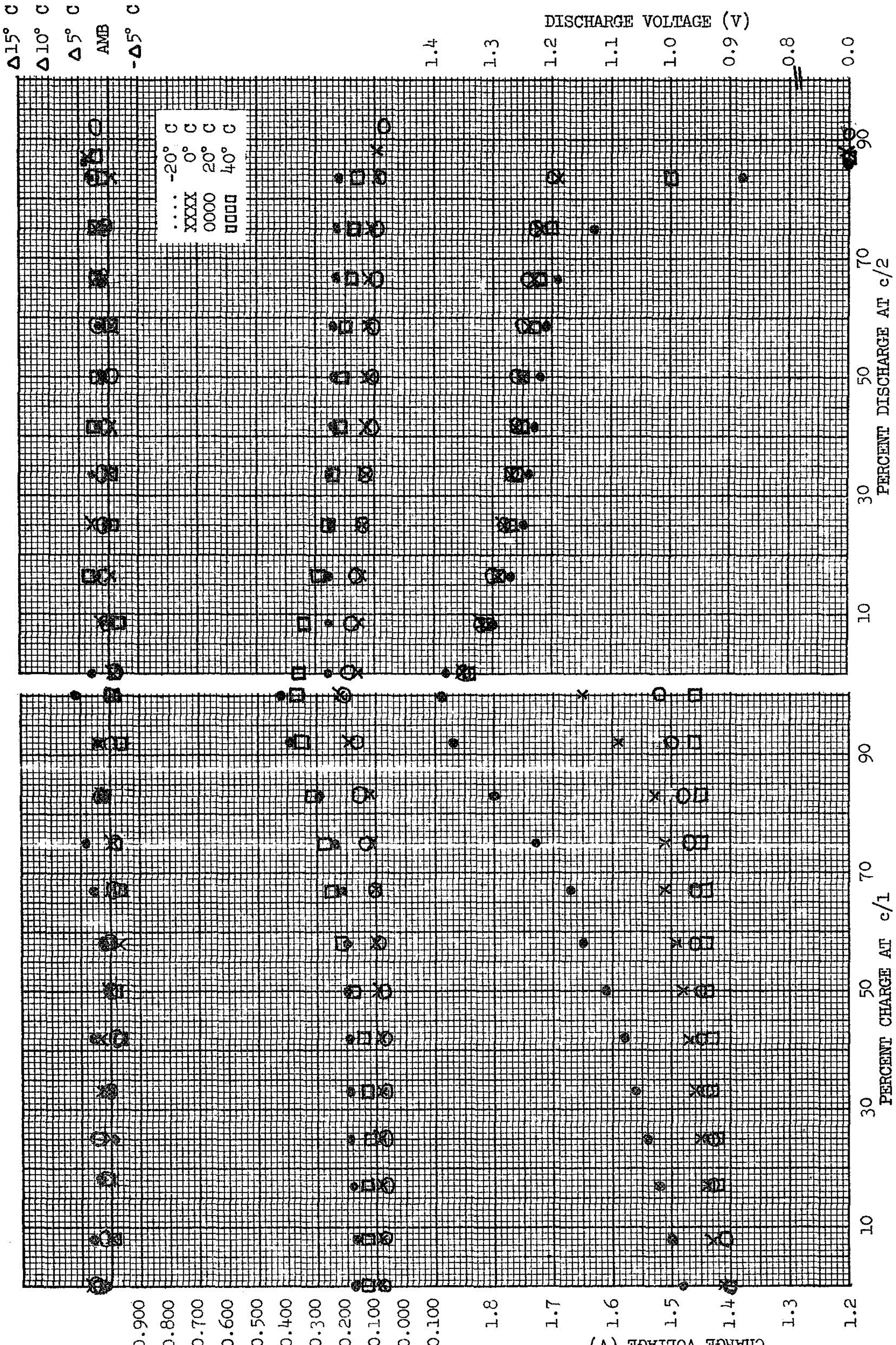

Δ15° C
Δ10° C
Δ5° C
AMB
-Δ5° C
DISCHARGE VOLTAGE (V)
.... -20° C
XXXX 0° C
0000 20° C
□□□□ 40° C
PERCENT DISCHARGE AT c/2
PERCENT CHARGE AT c/2
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY
AUXILIARY ELECTRODE (MV)
CHARGE VOLTAGE (V)

FIGURE 5




VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 6

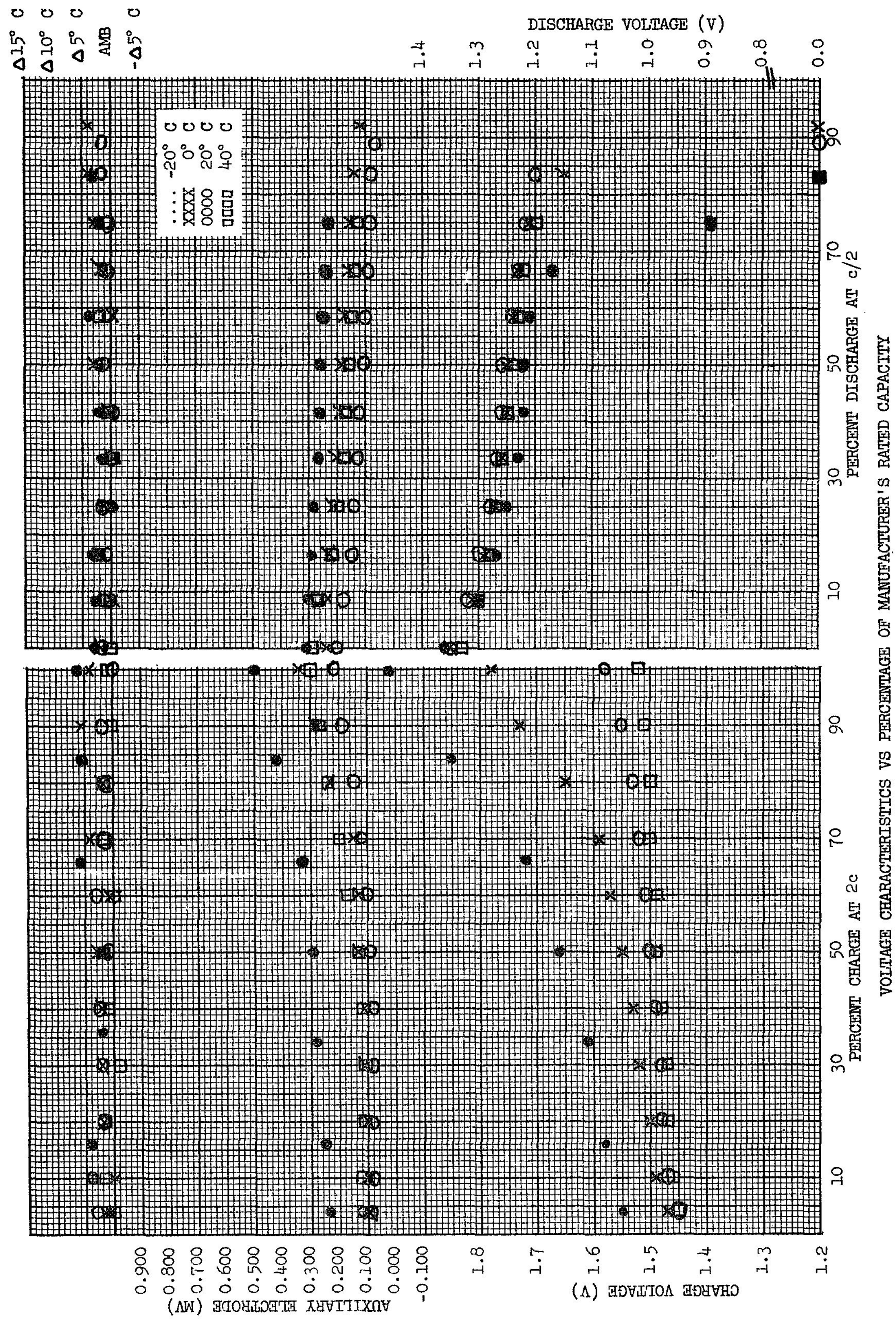

Δ15° C
Δ10° C
Δ5° C
AMB
-Δ5° C
DISCHARGE VOLTAGE (V)
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.0
.... -20° C
XXXX 0° C
OOOO 20° C
□□□□ 40° C
PERCENT DISCHARGE AT c/2
PERCENT CHARGE AT 2c
10
30
50
70
90
VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY
AUXILIARY ELECTRODE (MV)
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
CHARGE VOLTAGE (V)
1.8
1.7
1.6
1.5
1.4
1.3
1.2

FIGURE 7

DETERMINATION OF MOST EFFICIENT CHARGE RATES
CAPACITY VS CHARGE RATES

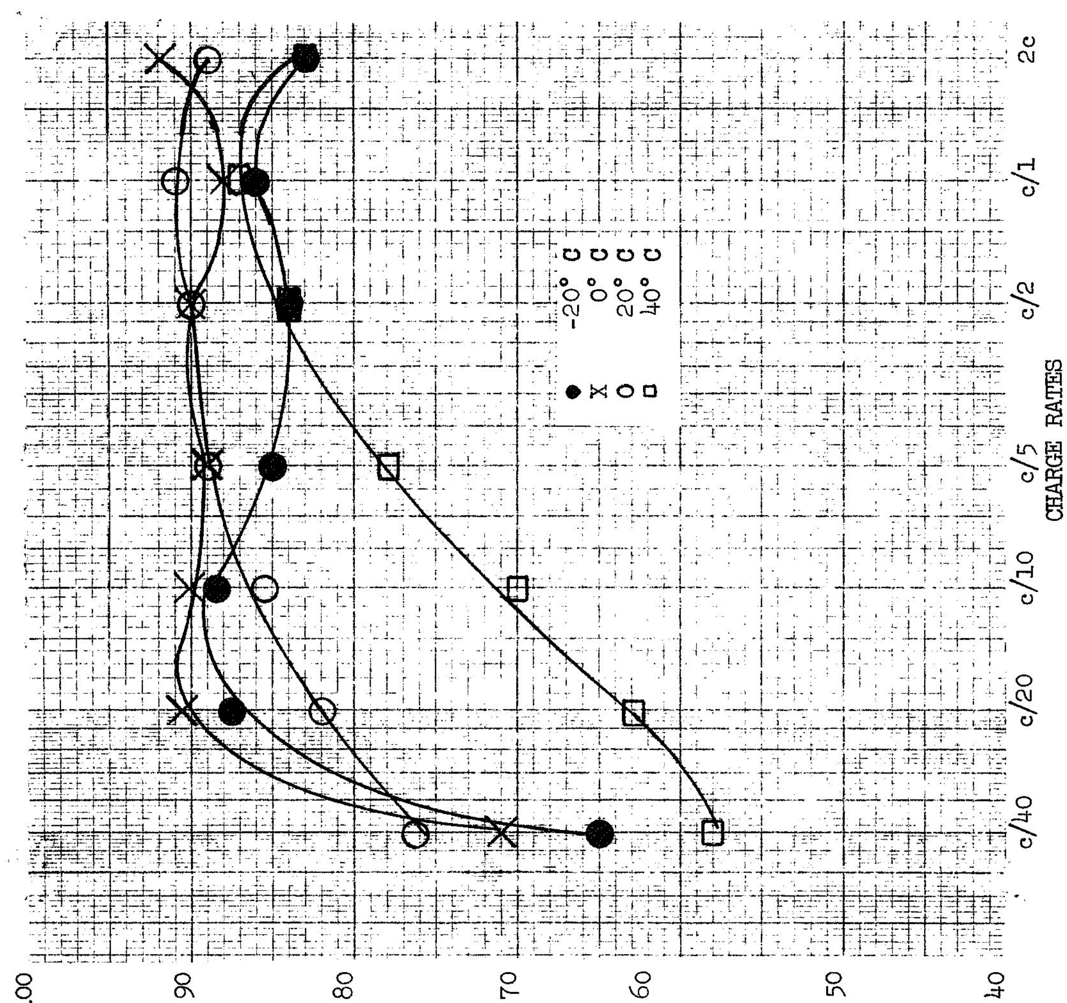



FIGURE 8

END OF CHARGE VOLTAGE CHARACTERISTICS VS RATE OF CHARGE

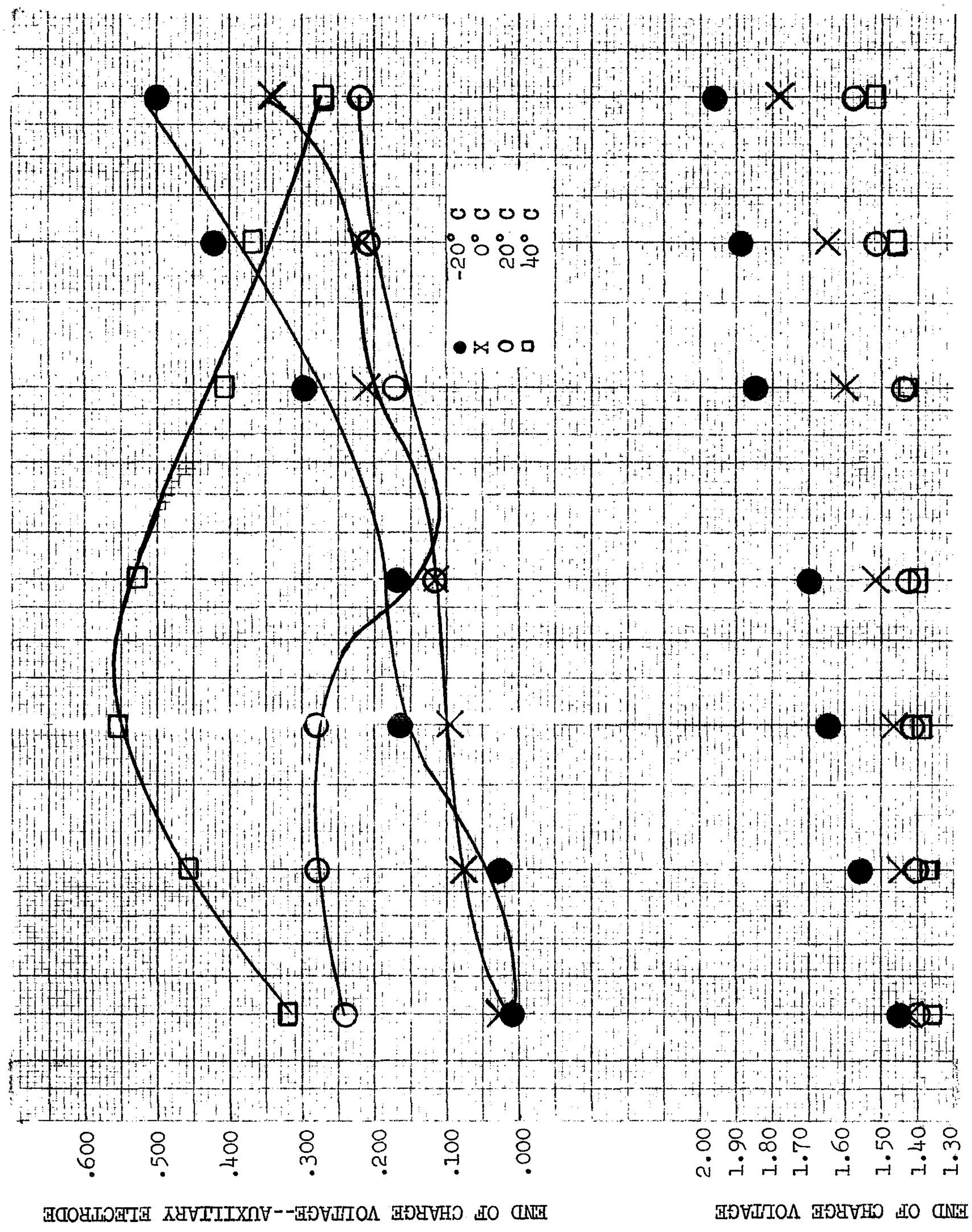
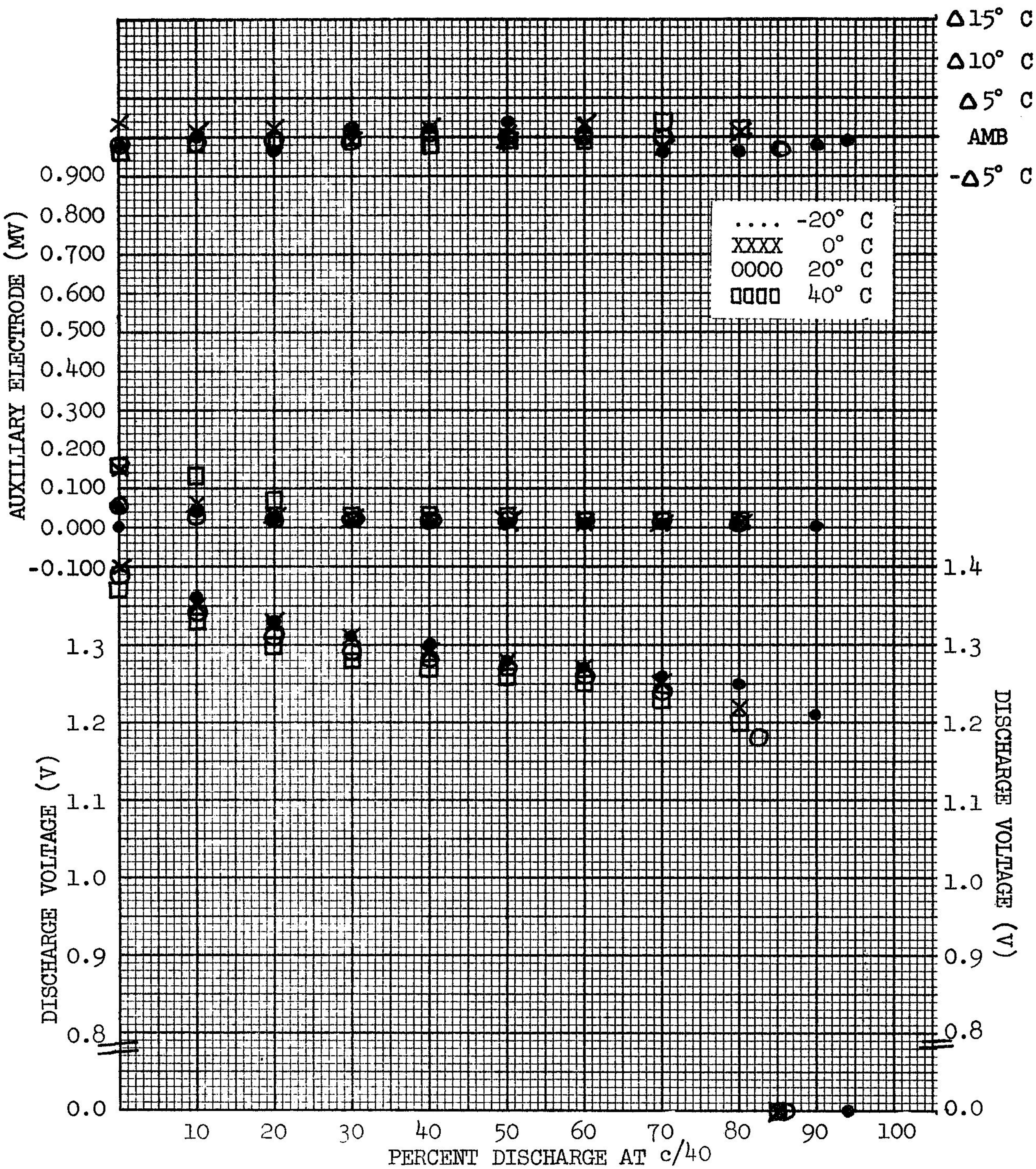
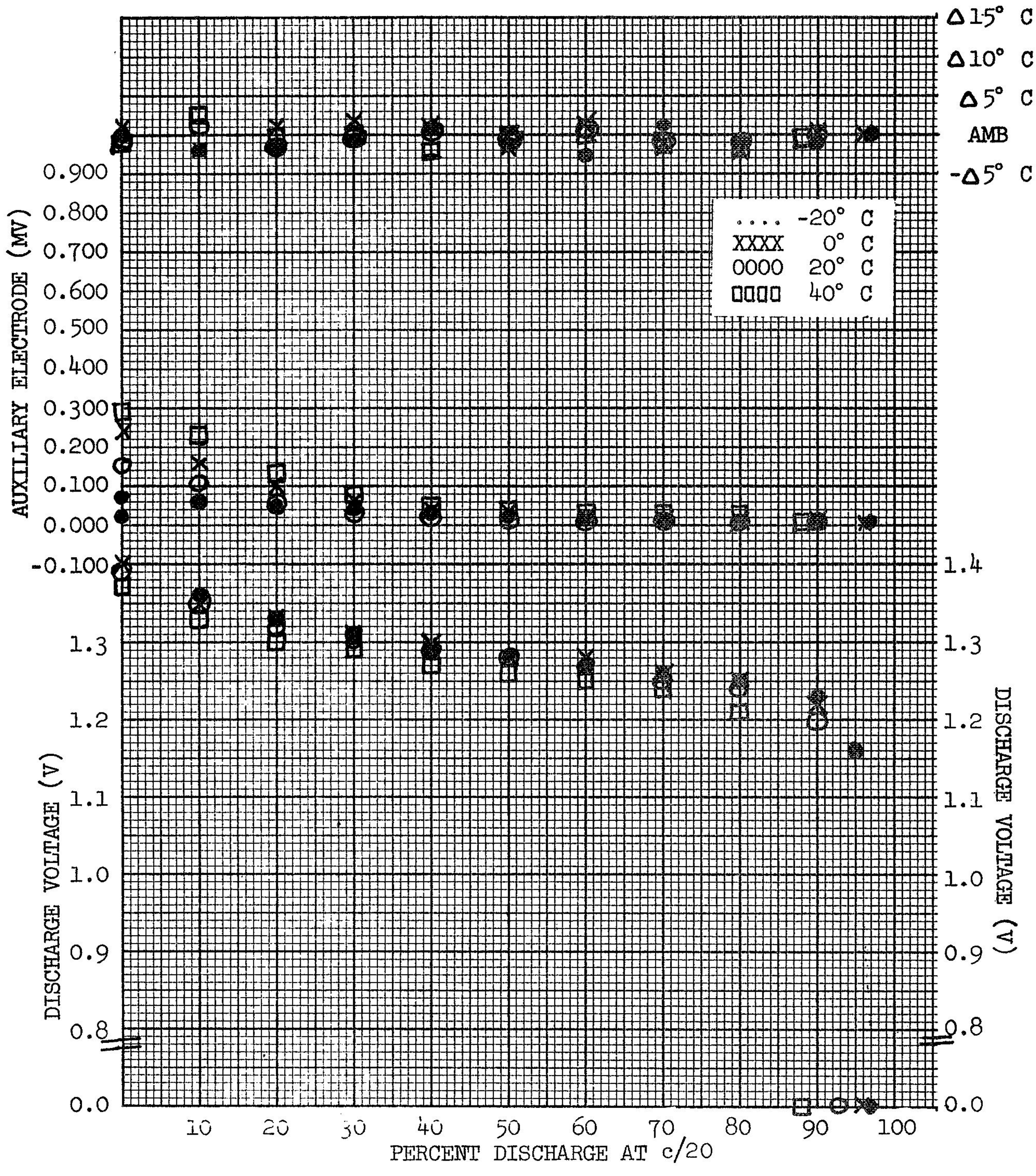



FIGURE 9



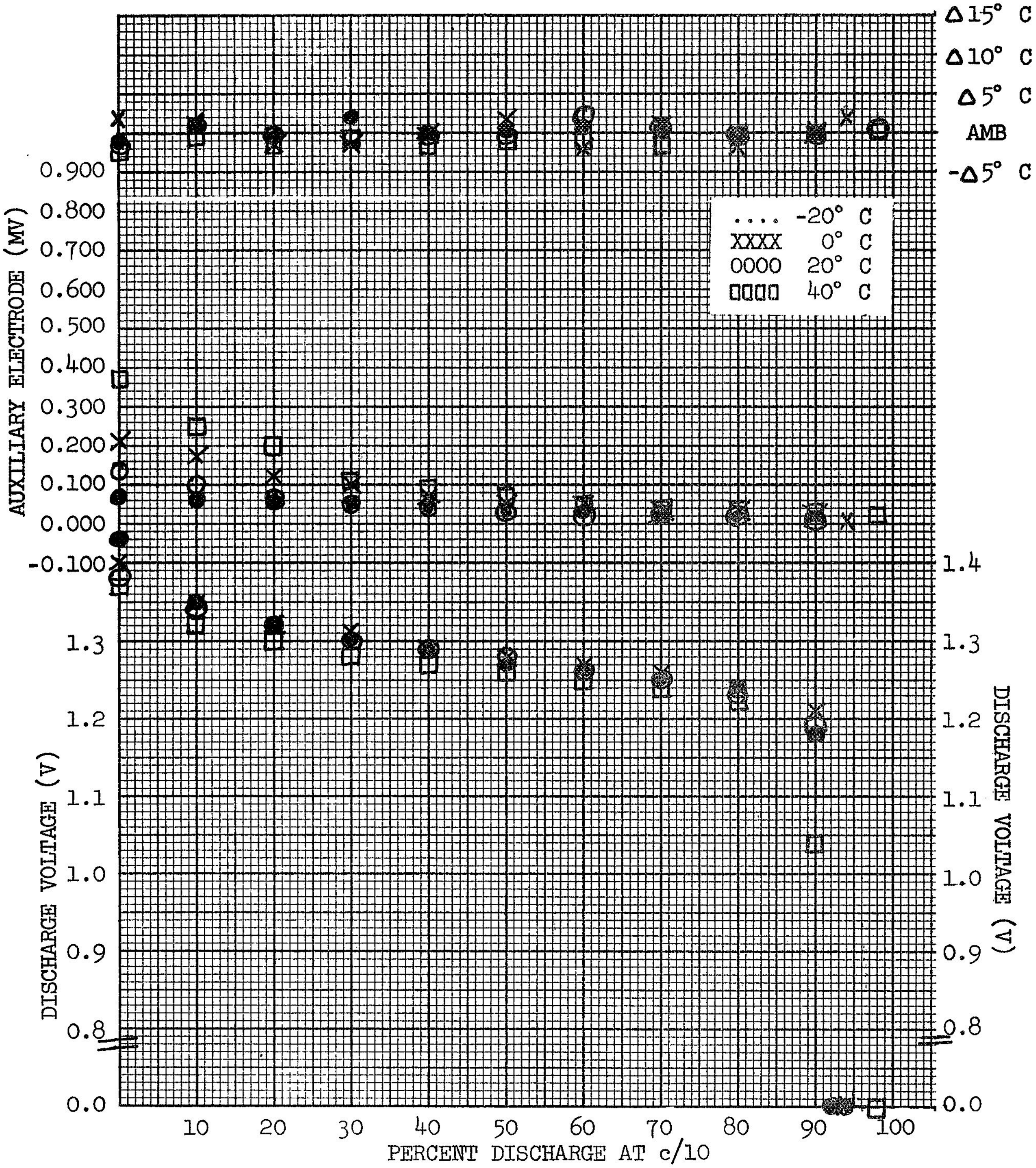

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 10



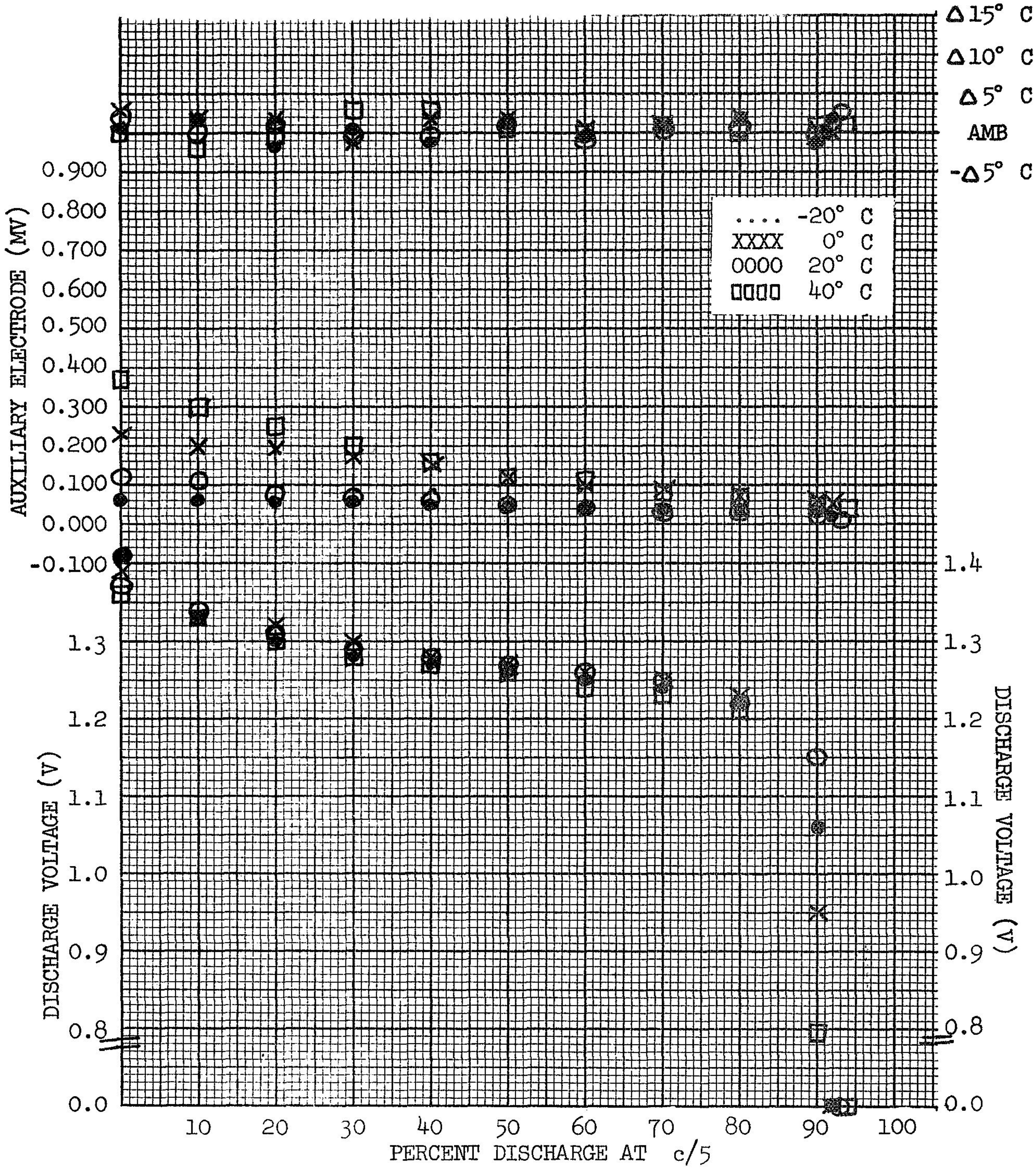

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 11



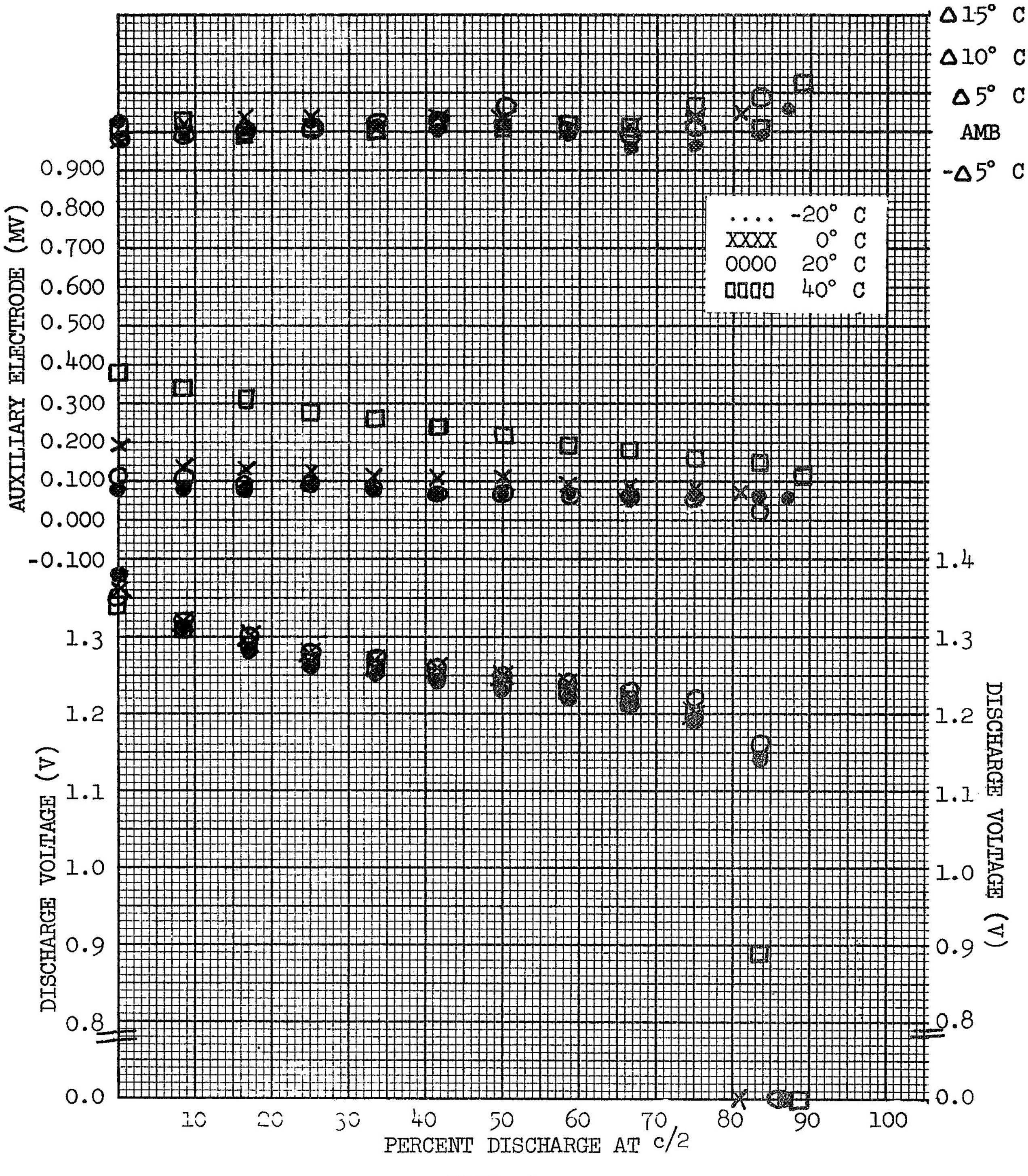

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 12



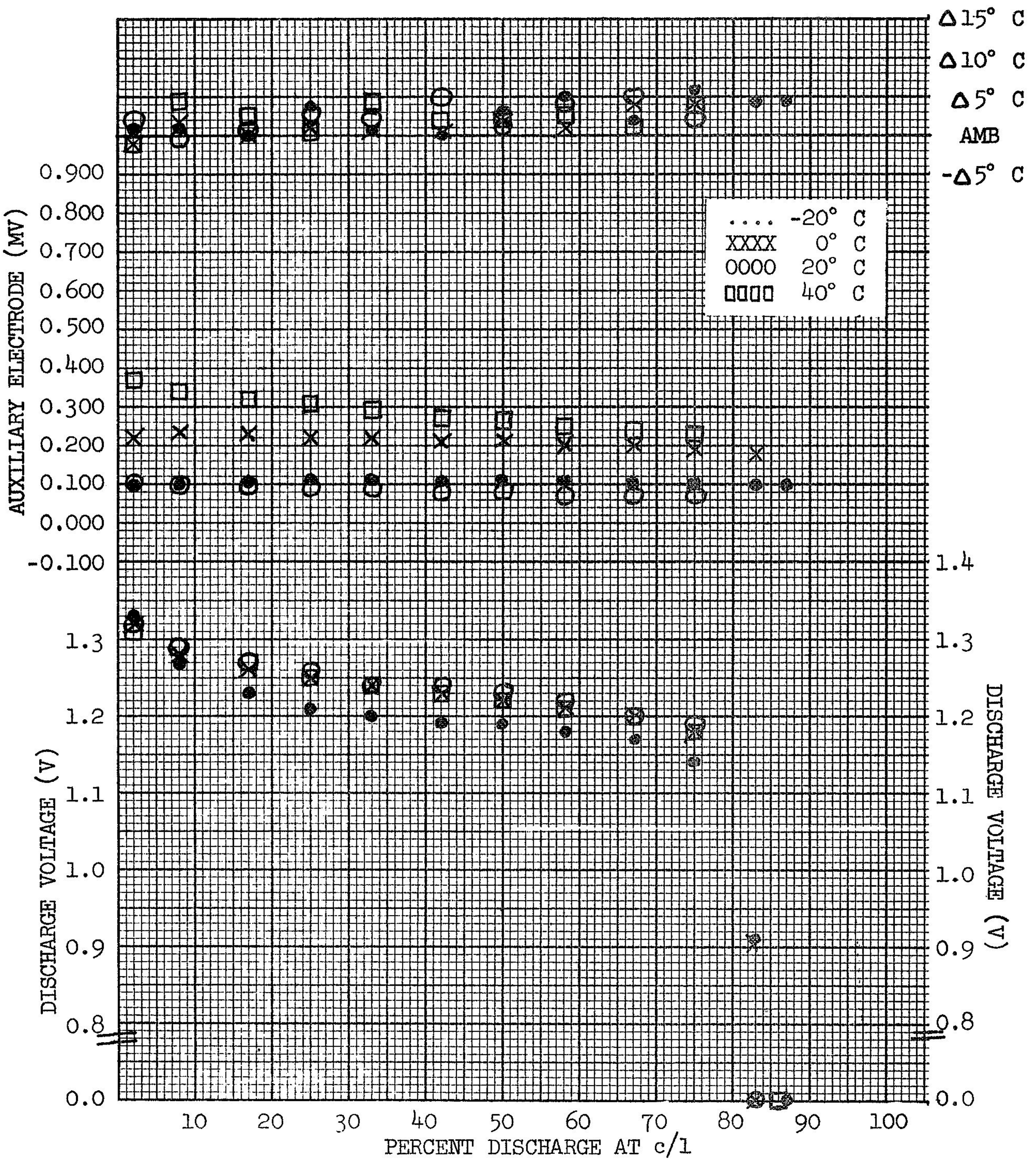

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 13



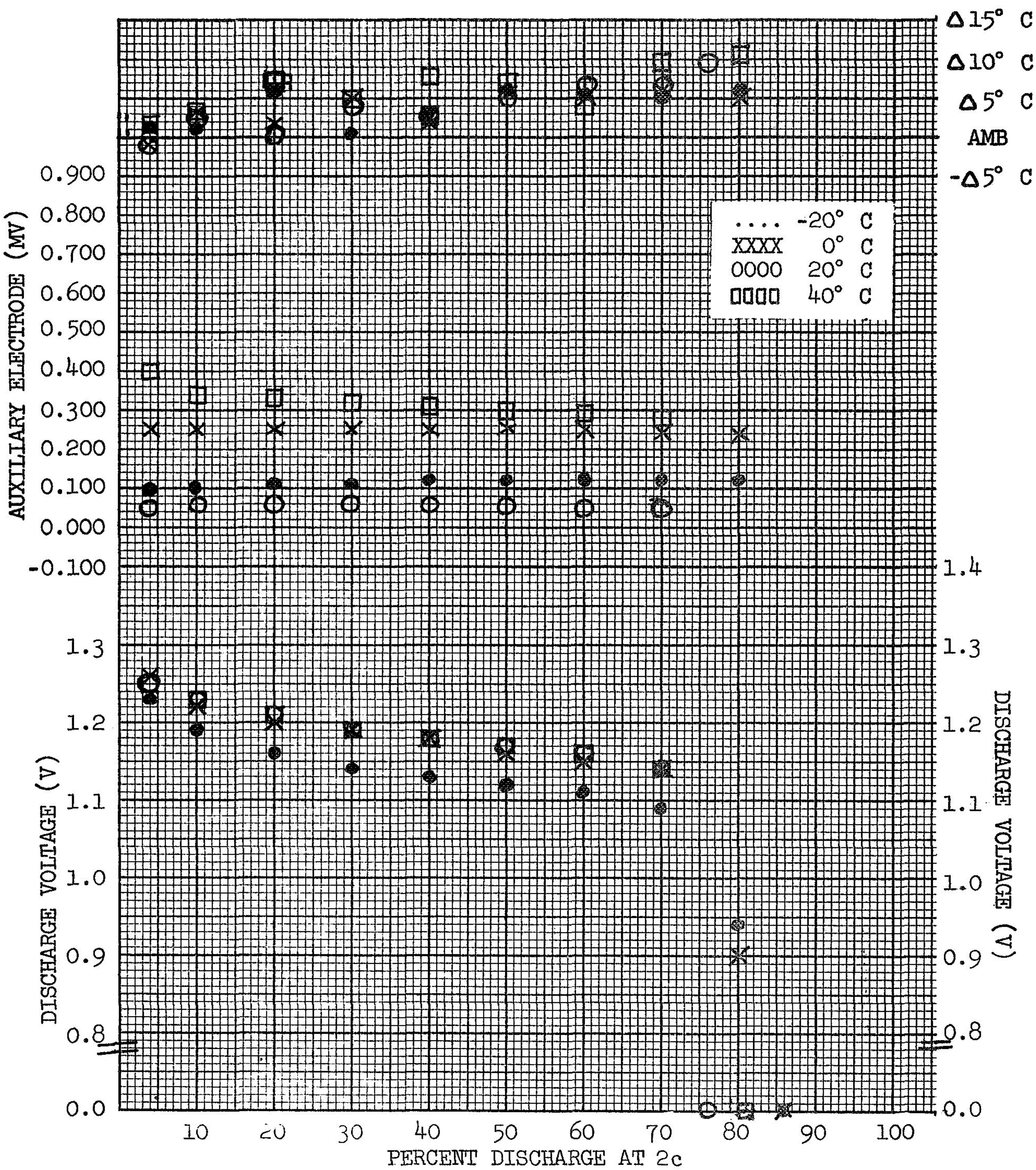

VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 14




VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 15




VOLTAGE CHARACTERISTICS VS PERCENTAGE OF MANUFACTURER'S RATED CAPACITY

FIGURE 16

DETERMINATION OF MAXIMUM CAPACITY
PERCENT OF RATED CAPACITY VS DISCHARGE RATES

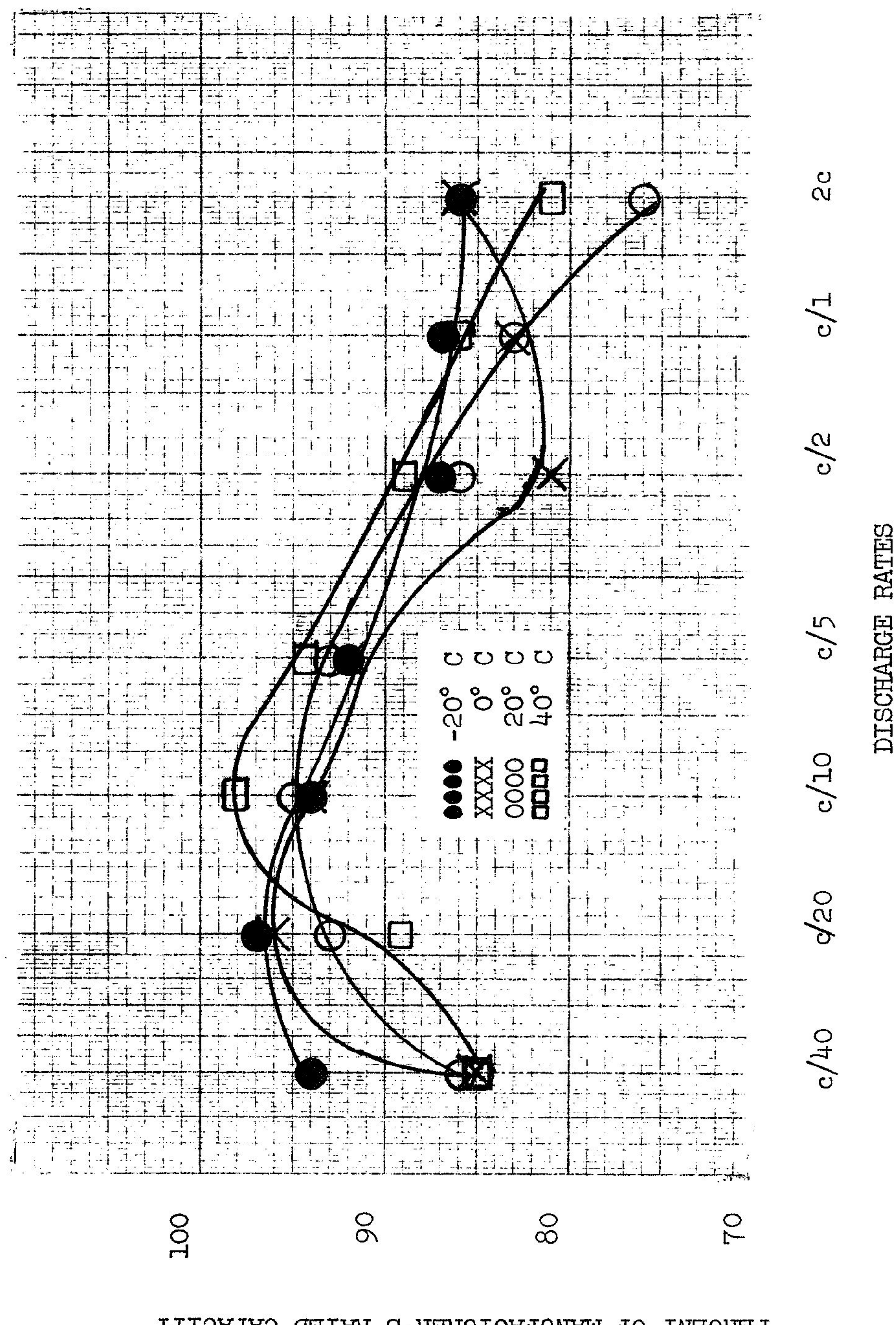



FIGURE 17

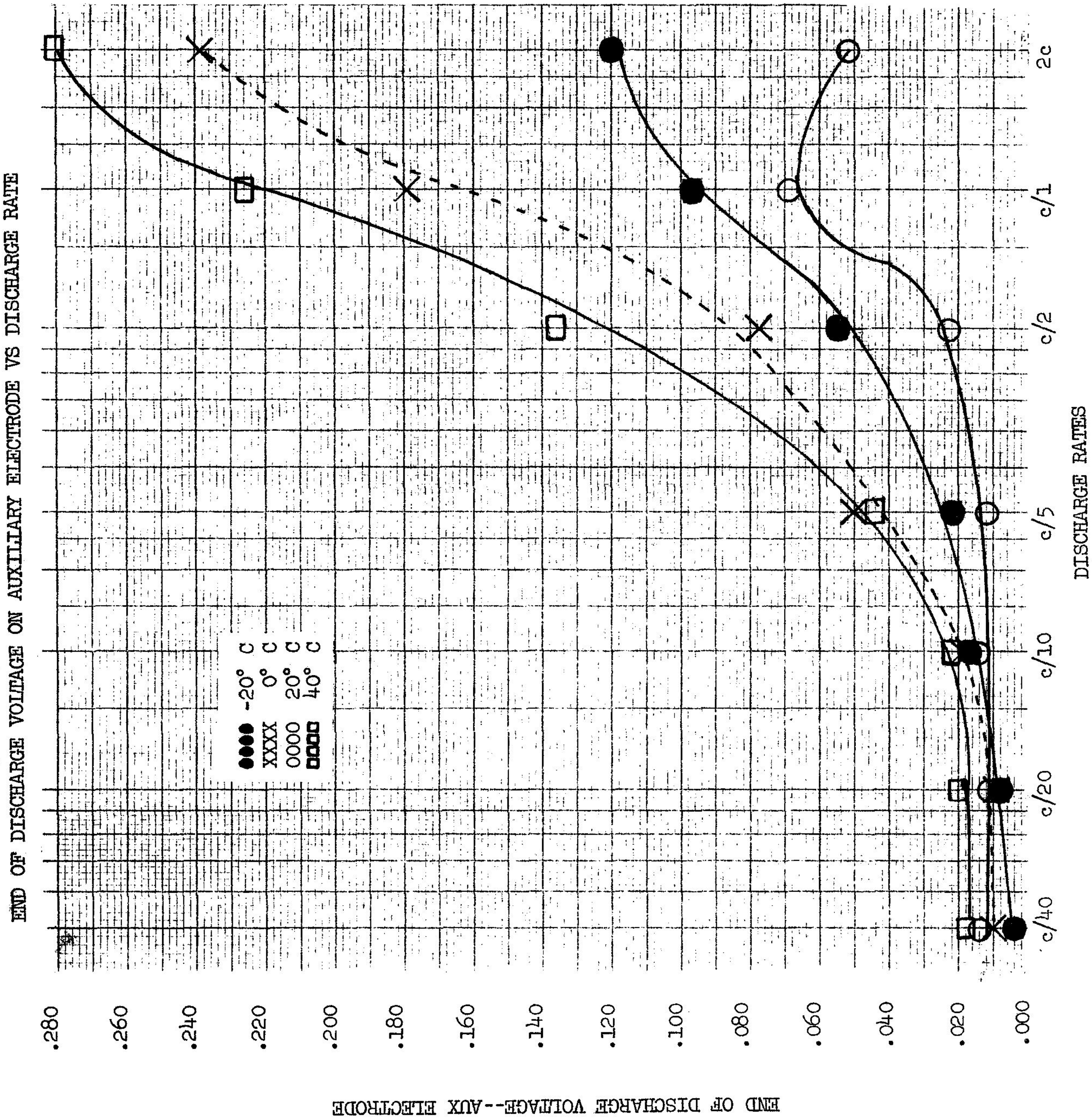

END OF DISCHARGE VOLTAGE ON AUXILIARY ELECTRODE VS DISCHARGE RATE
●●●● -20° C
XXXX 0° C
OOOO 20° C
□□□□ 40° C
c/40
c/20
c/10
c/5
c/2
c/1
2c
DISCHARGE RATES
.280
.260
.240
.220
.200
.180
.160
.140
.120
.100
.080
.060
.040
.020
.000
END OF DISCHARGE VOLTAGE--AUX ELECTRODE

FIGURE 18

OVERCHARGE VOLTAGE VS. CHARGE RATES

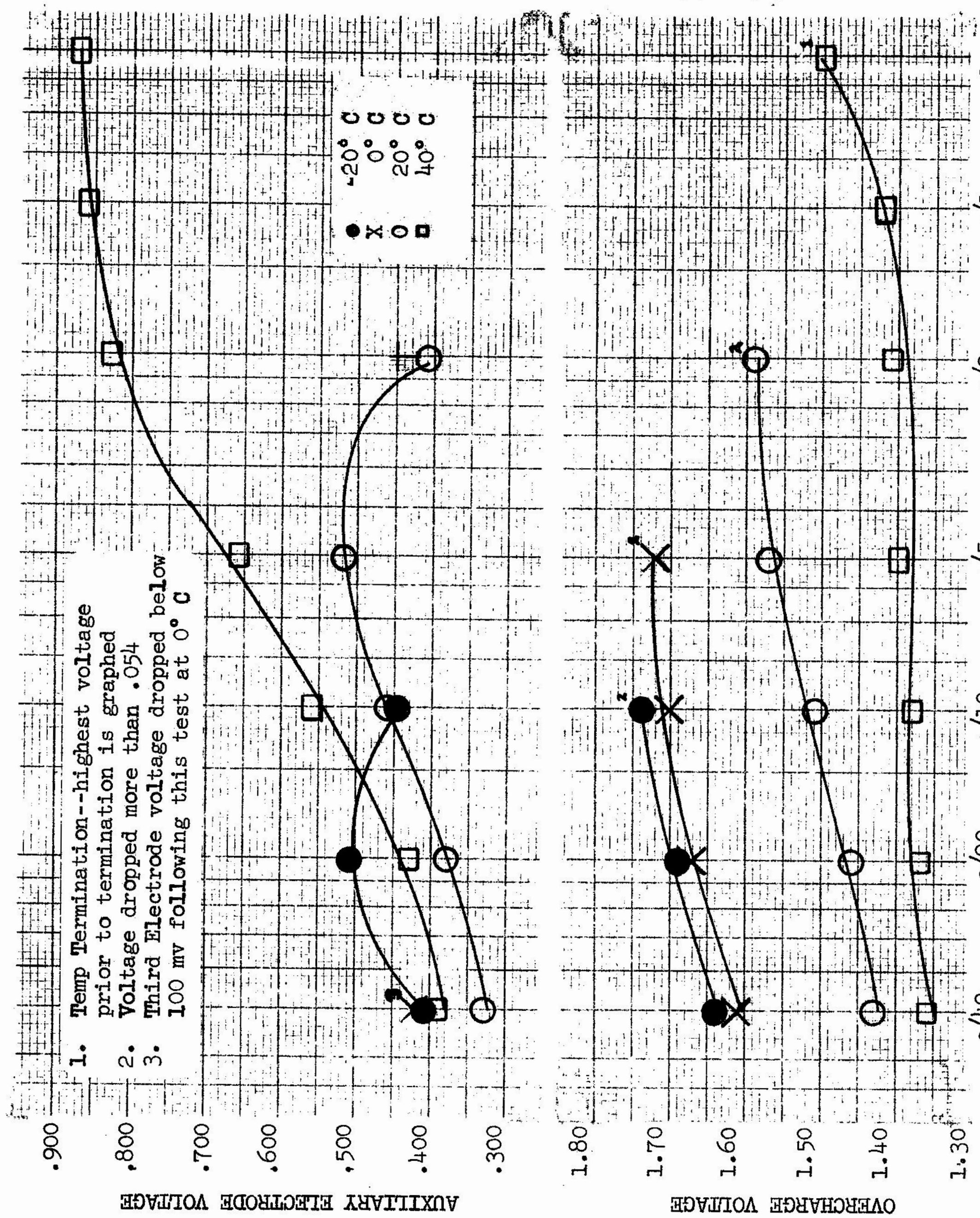



FIGURE 19

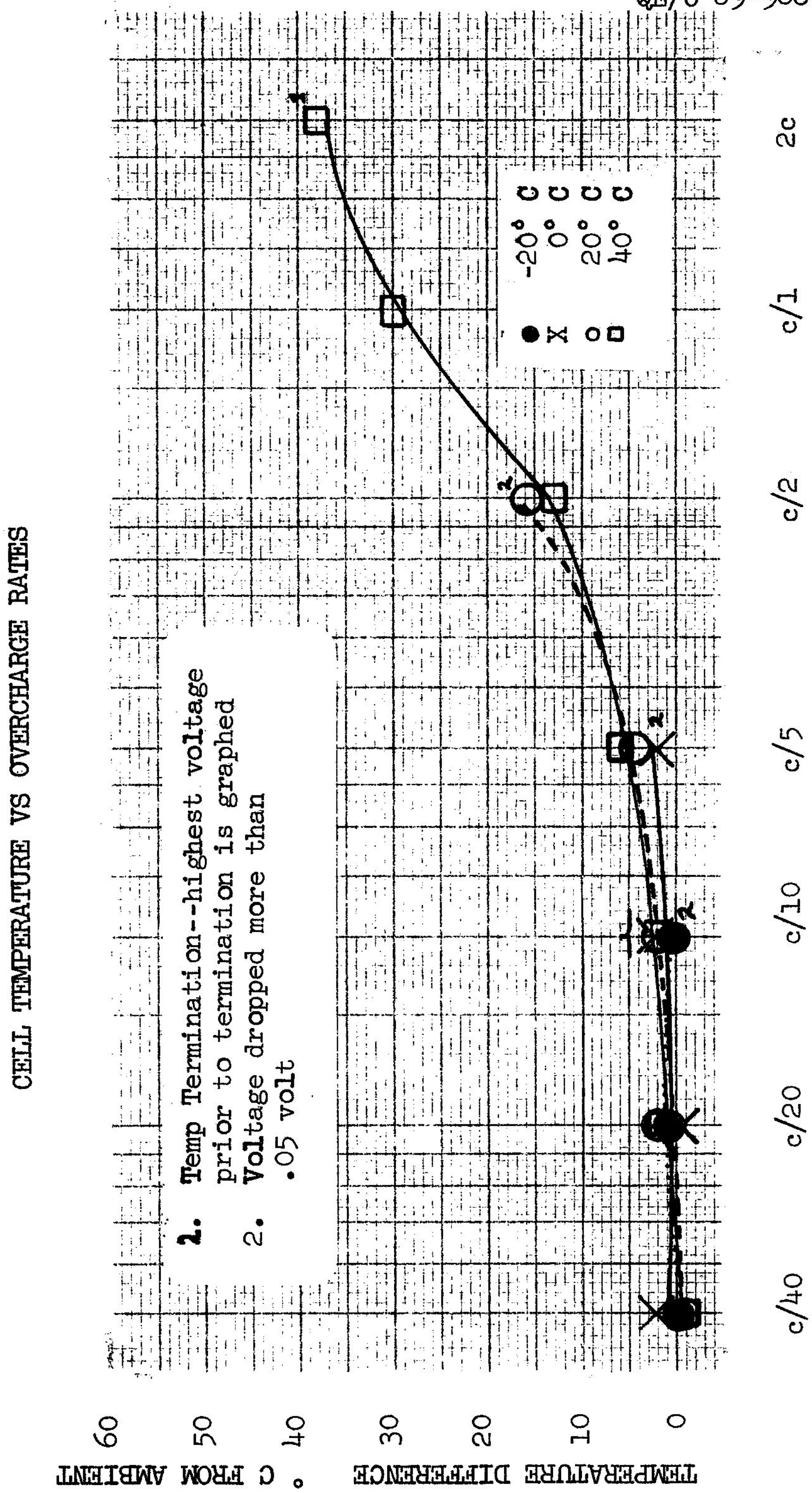

CELL TEMPERATURE VS OVERCHARGE RATES
1. Temp Termination--highest voltage prior to termination is graphed
2. Voltage dropped more than .05 volt
● -20° C
X 0° C
o 20° C
□ 40° C
c/40
c/20
c/10
c/5
c/2
c/1
2c
0
10
20
30
40
50
60
TEMPERATURE DIFFERENCE ° C FROM AMBIENT

FIGURE 20

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